BACK

Dam Break Flood Risk and Safety Management at Downstream Valleys

A Portuguese Integrated Research Project

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Dams, like "all structures, will be broken in the end - just as all people will die in the future. It is the purpose of the medicine and engineering to postpone these occurrence for a decent interval". (J. F. Gordon)

1. INTRODUCTION

The presentation describes a research project now under development in Portugal funded by the NATO Science for Stability Programme. This particular project is titled **Dam Break Flood Risk Management** in **Portugal,** code NATO PO-FLOODRISK PROJECT. The project began in 1994 and will end in the fall of 1999. The research institutions involved are:

Laboratório Nacional de Engenharia Civil (LNEC) or Civil Engineering National Laboratory;

Instituto Superior Técnico (IST) or Technical Superior Institute

The project has the following supporting institutions:

Instituto da Água (INAG) or Water Institute, the Portuguese water and dam safety authority;

Electricidade de Portugal (EDP) or Portuguese Electricity, the main power company of Portugal;

Serviço Nacional de Protecção Civil (SNPC) or Civil Protection National Service, the Portuguese agency for coordination of civil protection actions.

The presentation includes the objectives and concepts that inspire this research work, the project structure and developments, and the expected contributions.

The environmental safety and the social behavior under risk stress have been topics for three decades, and as the result of a few dramatic dam accidents in the world, the dam safety regulations introduce some procedures related to downstream protection, including inundation maps, zoning, emergency and evacuation plans. In a very populated valley with large cities, the implementation of these procedures will not be easy should a crisis occur. Within this context a group of researchers planned, in 1993, this NATO project.

2. GENERAL OBJECTIVES

At a national level the project intends to improve the Portuguese operational implementation of the dam safety regulation published in 1990. At a scientific and technical level the aim is to develop new concepts and methodologies for integrated dam and valley risk management.

The following four general objectives of the project were chosen in order to inspire the research work:

> To improve the engineering capability for dam break flow analysis and prediction on real complex situations, as well as to improve the use of social sciences in dam risk management.
>
> To develop methodologies and guidelines for dam break flood risk management in Portugal, as a first step toward a new integrated flood safety system based on structural and non-structural measures, including public participation, and on advanced information support.
>
> To implement new advanced information technologies applied to hydraulic engineering analysis and land-use and safety management techniques.
>
> To create a new concept for operational crisis control and integrated dam safety management, and also to contribute to improvement of the Portuguese dam safety regulation and land-use management in risk-prone areas.

Each of the actors should have a part in global safety responsibility. The valley development and the land-use policy downstream of a built dam can modify the initial risk level. This needs to be accepted by local authorities on behalf of the public.

3. EMERGENT CONCEPTS

- The Integrated Dam and Downstream Valley System (DDVS)

  The DDVS includes the dam-reservoir system and the downstream valley system, including the inhabitants, human feelings, and public participation.

  In the valley an adaptative land-use management plan, based on flood zoning, and efficient civil protection procedures are fundamental techniques of risk management.

- The Shared Downstream Risk Level (SDRL)

  The shared responsibility toward risk management is a new concept to be implemented between dam owners, authorities, and the public (Figure 1).

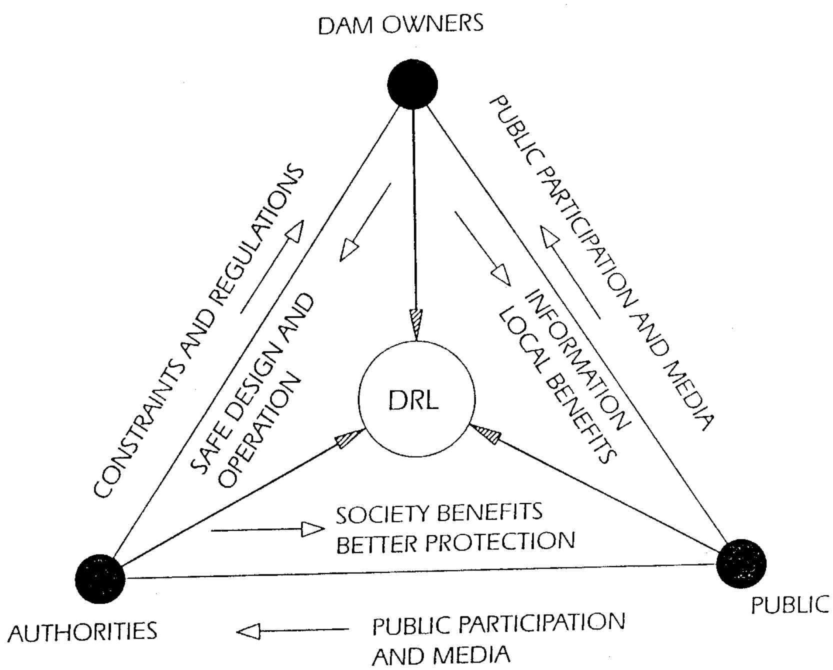

Fig. 1 - DRL - Downstream risk level accepted and shared by the three actors

These three main actors will try to reach a downstream risk level accepted and shared by them. The authorities will impose constraints and regulations to dam owners expecting to receive from them a safe design and operation. The public and the media have now a strong influence on dam owners and authorities during the main phases of a large dam lifetime. They expect to receive information, local and global benefits, as well as better protection from accidents or incidents.

This shared responsibility will need a better understanding of dam safety and risk perception and of what is an effective protection against an abnormal flood.

The NATO project developed in the context of an integrated methodology for dam break flood risk and safety management at downstream valleys is supposed to include:

Computational modeling and simulation systems

On-line multimedia databases

A Geographical Information System (GIS)

Applied social sciences techniques, strongly dependent on local and regional cultural characteristics and human behavior

The integrated dam safety concept is now supported by three pillars:

Technical-operational

Monitoring

Emergency and risk management

The first one includes the dam design, construction, and exploitation and will try to minimize the failure probability. The second one gives the opportunity to observe and control the dam behavior. The third one includes the planning and organization along the valley and all emergency procedures in order to anticipate and mitigate the downstream dangers should a dam accident occur. The objective of the project is to develop new methodologies for this third aspect.

4. PROJECT STRUCTURE

The NATO project is organized in five sub-projects (Figure 2):

Sub-project 1 - Hydraulic analysis and computational simulation

Sub-project 2 - Dam and reservoir safety analysis

Sub-project 3 - Social impact of dam break risk

Sub-project 4 - Computer-aided decision support system

Sub-project 5 - Integrated emergency and training system

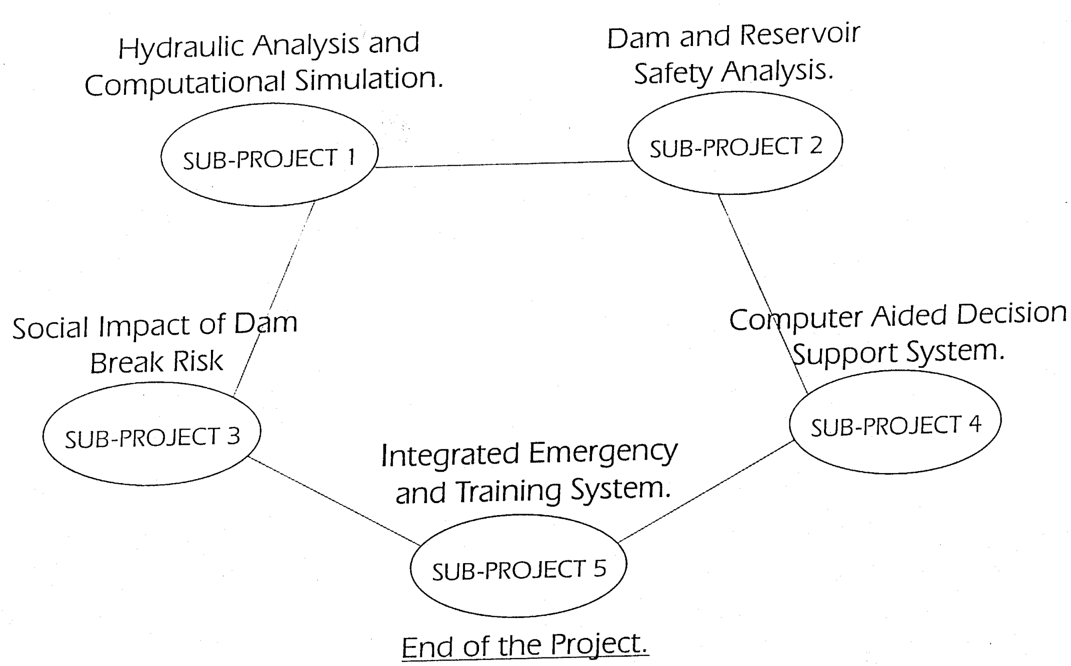

Fig. 2 - NATO Project Structure

In **Sub-project 1,** dam break flood computational models were developed for natural irregular valleys (one-dimensional and two-dimensional models) based on the MacCormack-TVD high resolution numerical scheme. This technique allows the numerical simulation of significant flow discontinuities as those due to a bore advancing through the valley after a sudden dam burst. Large instabilities, as well as numerical fluctuations, are strongly attenuated or even eliminated. To validate the computational models, a set of experiments was executed in an experimental test facility at LNEC (Figure 3). Another topic under study is concerned with the unsteady sediment transport during a dam break flood. For field work and tests an experimental area was selected as a case study: the Arade valley in Algarve, near the coast in south of Portugal, where two dams are built (an earth dam and a concrete arch dam).

In flood plains the 2-D model can give a more accurate solution, and this will be very important in what concerns the inundation mapping (Figure 4). The experiment is being modeled by a large physical model where, in the near future, special hydrodynamic problems will be studied, as well as tests for validation of computational models.

Sub-project 2 will develop design and risk criteria for practical dam break analysis, as well as the dam rupture scenario for flood simulation, including hydrologic conditions, breaching and dam data, and recommendations according to dam safety regulations. These criteria as well as the dam break flood simulations will make it possible to have inundation maps for risk management and social impact of risk. These studies include the following topics:

Public perception and valley risk vulnerability

Sociological analysis and characteristics guidelines

Planning tools for land-use management

Public participation studies

The contribution of the social research group **(sub-project 3)** to the process of dam safety and emergency planning is:

Description of the population in demographic, economic, housing, and social terms

Knowledge of dam break flood risk perception in order to help in promotion of safety management and in risk communication

The tasks developed to achieve the first goal include the description of physical and social aspects of human occupation, along the Arade experimental valley, in flood-prone areas.

To achieve the second goal, the tasks developed for assessment of public perception of dam break flood included the collection of information on public perception, public pre-paredness and adjustments in a sample of the target population:

State of population (number, structure and density)

Description of households (number, structure and density)

Sociographic characterization (economical status and educational level)

Housing conditions (number buildings, building typology, and number of family buildings)

Exploratory interviews of people living in the experimental valley

Content analysis of interviews and data statistical analysis

Construction of questionnaires to be applied to a representative sample of population at risk

The theoretical perspective undertaken in this analysis is multilevel and can be summarized in four points:

1. Lay conceptions for risk

   The perception of flood risk and dam failure risk (a low probability high consequences risk) seems particularly relevant.

2. Continuous exposure to uncontrollable threat modifies risk estimations

   It is therefore expected that residents living under high objective risk will minimize their probabilities of damage in case of dam break.

3. Risk perception is not isolated from other socially shared beliefs and representations

   These beliefs and representations make sense within the general conceptions of the environment, and it is expected that risk perception should be related to some more general conceptions of the dam, the science and responsibility of prevention.

4. Social roles of the different protagonists in risk management frame

   It is expected that farmers, engineers, decision-makers, and the public present different interests and perspectives in risk discourses.

The survey focuses this global perspective and the consequences of exposure to dam break risks and is intended to understand the following issues:

How does the population in the valley think about the dam failure risk?

How are the dams perceived by those residents?

The results present some challenge in terms of risk communication and open some perspectives toward its content:

1. As dam failure risk is perceived as a much more dramatic, uncontrollable, and unfamiliar risk than a normal flood risk, it is more difficult to be accepted by population. The flood warning system to be created should then be developed for

floods in general, dam failure being a particular and extreme case of flood. This strategy would have several other important consequences: it would prevent damage in case of natural floods or dam spillouts, and the population could have more opportunities to learn preventive behavior.

2. Risk communication should not be conceived as a one-way strategy. In order to promote effective responses to warning systems, the decision process of the individuals must be understood and the residents should be informed about the seriousness of the risks they face and their possibility of response in adequate time. To fulfill these goals in case study, where the population is living at risk for more than 40 years, direct communication is particularly desirable. Furthermore, a local committee of residents in risk areas could help to improve the dialog between the experts and the public, and prevent avoidant or hypervigilant responses.

3. Given the striking differences in flood and dam risk perception from the residents near the coast and near the dam, the communication strategy should be distinct in the two sites. Floods have different characteristics in the two areas, and they should be addressed separately.

4. Rural/urban distinctions are also important both in our results and in the literature of warning response. However, as the differences relate mainly to the age and degree of literacy of the subjects, they only affect the communication channel and not the content of message.

Another aspect included in **Sub-project 3** is the land-use management decision system. The study is concerned with:

Study of the interface between risk management and land-use planning techniques.

Development of methods to be used by local and regional authorities integrating flood risk planning in valley management.

Development of risk awareness among land-use planners and authorities that are responsible for location of infrastructures and public services, and improve the application of these techniques.

In **Sub-project 4** a decision support system is developed including:

a dam safety database (*Dam Map Generator*);

a GIS development and implementation (*Daminfo*);

an integrated architecture for a decision system.

DamInfo gives water managers and civil protection agents an easy access to dam-related data. *DamInfo* makes decisions on how to exploit the dam and on which measures and actions to take in an emergency situation much easier and more technically supported.

Dam Map Generator helps the project team to automatically create new maps as well as to run dam break models and visualize their results.

Finally **Sub-project 5** will produce:

integrated crisis management guidelines

downstream valley safety guidelines

field exercises applied to the case study - Arade River

5. VALLEY VULNERABILITY

Vulnerability is one of the major concepts in valley risk management as safety factor is important for dam design. Vulnerability can be defined as a measure of the level of exposure and of damage susceptibility toward the dam break flood.

A global index should include both the physical vulnerability, as well as the socioeconomic vulnerability. The level of vulnerability should be obtained for each sub-zone downstream of the dam.

The physical vulnerability should include a quantification of the dam break flood impact as a function of variables like the following:

maximum depth (D)

maximum flow power (V*D)

maximum depth gradient (DD/DT)

The socioeconomic vulnerability will be a weighted function of several characteristics factors:

Social

- Families (number of members)
- Individual (age, education)

Property

- Buildings
- Economic activities

Strategic Infrastructures

- Power and water networks
- Hospitals

Warning and Emergency System (effectiveness)

Civil Protection Response (effectiveness including training)

Psycho-social (public perception)

The global valley index obtained from the inundation map can be an indicator of valley situation in what concerns land-use planning, crisis management, warning evacuation planning, emergency plan, and training exercises.

6. IMPORTANCE OF DAM BREACH MECHANISM

In the context of the Interagency Dam Breach Workshop and of the activities of the NATO Project, a better knowledge of the breach mechanism is very important. In what concerns the earthfill dams, there a few computational models for simulation of the physical process. In engineering practice the BREACH model developed by D. Fread is the most popular.

Based on Kast and Bieberstein (1997), the breach models can be classified as follows:

> Type A: the breach outflow is calculated as a worst-case-scenario for all types of dams. It is assumed the breach has the size of the whole dam from the beginning of the event.
>
> Type B: the breach outflow is calculated with a breach of a chosen and fixed shape and size (a technique also applied to concrete dam breaches).
>
> Type C: the models take into consideration the time-dependent process development of the breach in an earthfill dam. The breach enlargement is calculated as a function of a variety of parameters taking into account different aspects like breach hydraulics, sediment transport, geotechnical stability.

The last group of models (type C) can be sub-divided into three categories:

> Parametric models (e.g., DAMBREAK model of D. Fread and HEC-1 model)
>
> Physical-parametric models (e.g., Lou's model, BREED model or BREACH model)
>
> Stochastic models (Granoulis and Meon models)

The more developed models (type C models) try to describe the course of a dam break as exact as possible and take the delaying influence of the erosion process during a dam break into consideration. However, due to the complexity of the process, the resulting breach outflow hydrograph is still not very accurate. A sensitivity analysis is still needed. These models typically have a time step different from the one adopted in flood routing models. The choice of the breach model can depend on the objective of study:

> to simulate a more accurate outflow for flood mapping and for a risk assessment analysis;
>
> to support crisis management (including a potential evacuation action) during a dam incident with a threat of dam overtopping or piping;
>
> to reproduce a dam accident with failure and opening of a breach,

A more accurate breach model, in an earthfill dam, can attenuate the peak discharge and be used to modify the inundation map.

However, it is still difficult to have design criteria for the extreme envelope conditions. For risk management at downstream valleys, the inundation maps and the risk zoning need to be rather conservative. A better understanding of the breach inception and formation can be useful for the warning system and evacuation planning. Design criteria based on systematic physical and mathematical modeling can improve the capability of dam break simulations. For concrete arch dams a complete and sudden breach is typically considered. For concrete gravity dams a partial break is a more realistic model. However a sound criteria is still lacking.

A relatively large breach makes more important the inertial head effect on the outflow law. This topic was studied within the NATO project context. The quasi-steady behavior is accepted in orifice and weir modeling, but during a sudden dam breach, the hydrodynamic response of the weir formed in the breach is sensitive during a few times on the inertial head. In fact the net head on the breach will be:

$$H = H_S - H_I$$

with

$$H_I = l \; \frac{L_i}{g B_d H_r} * \frac{dQ_b}{dt}$$

where H_S = steady-steady head; H_I = inertial head; L_i = reservoir length under the hydrodynamic influence of the breach, B_d = dam span; h_r = reservoir depth upstream of the dam; g = gravity acceleration; Q_b = outflow discharge; l = a non-uniform effect correction coefficient.

This inertial head will allow an easier simulation of the Ritter problem with 1-D computational codes. In real cases the inertial effect will be important for very fast breach and large breach width (Viseu 1994). The influence of H_I will be greater during the first instants after the dam break (Figure 6) modifying the outflow law.

A better knowledge of the breach mechanisms will be very useful in order to work out effective plans for disaster or crisis management/control. The dam break delay due to a gradual breach inception can be vital for a suitable alarm and warning systems at downstream valley.

It is expected that the Concerted Action on Dam-Break (CADAM), now in progress in the UE, will develop the knowledge of dam break mechanisms and modeling.

7. EXPECTED PROJECT CONTRIBUTIONS

From this NATO project some general contributions to the improvement of safety for valleys downstream of dams are expected, as well as some answers to critical questions:

Better modeling techniques for hydrodynamic analysis. What improvements will be needed in engineering practice?

More effective dam safety regulations in what concerns the valley protection. How good are the present regulations?

Better integration of social and psycho-social variables into the risk management process. Will it be possible to reach compatibility between hard and soft applied sciences?

A contribution for an integrated risk and crisis management based on computer-aided techniques. How far can we go without falling into overkilling techniques?

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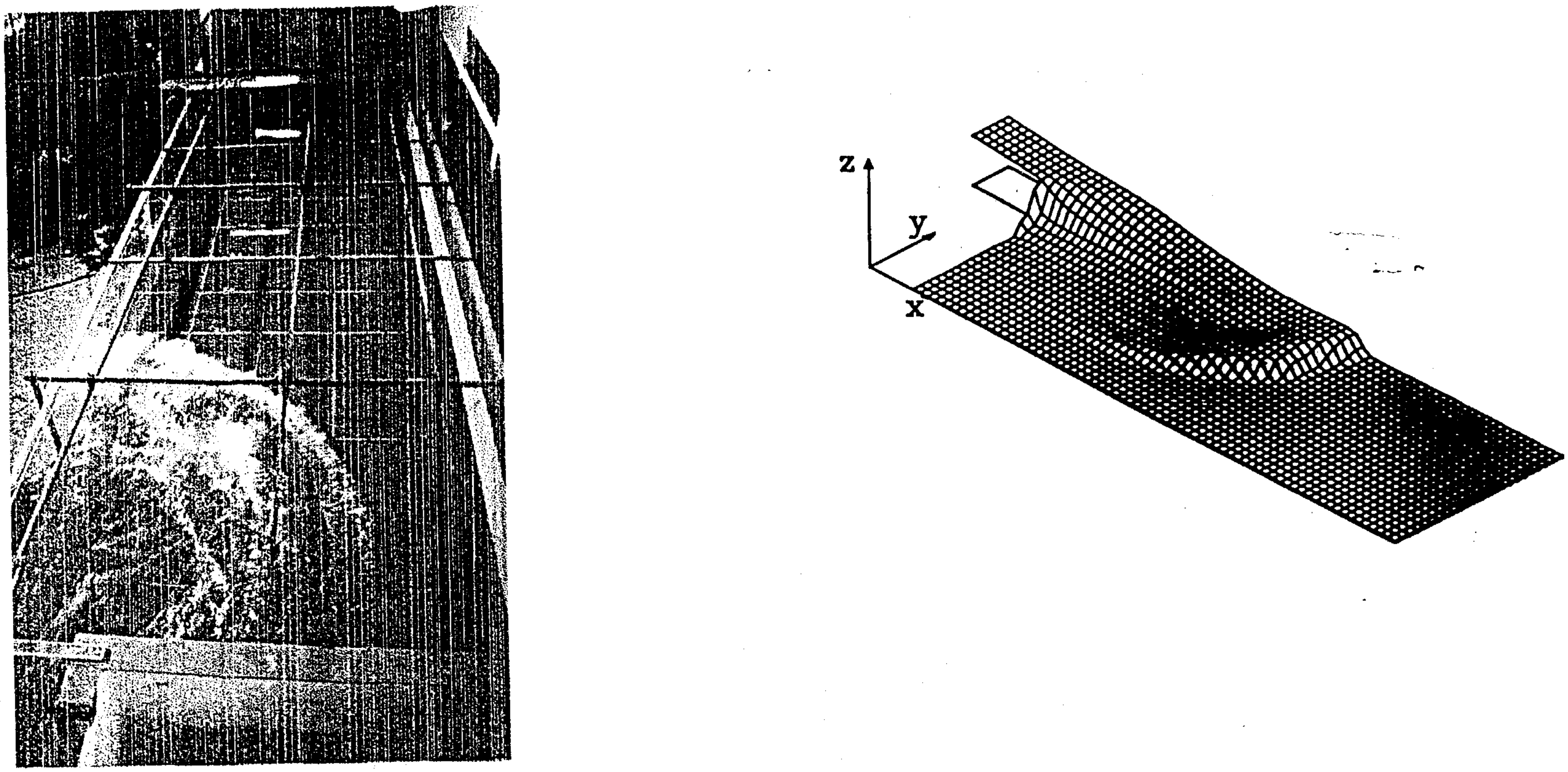

Fig. 3 - Experimental studies and 2-D computational simulations of dam break floods

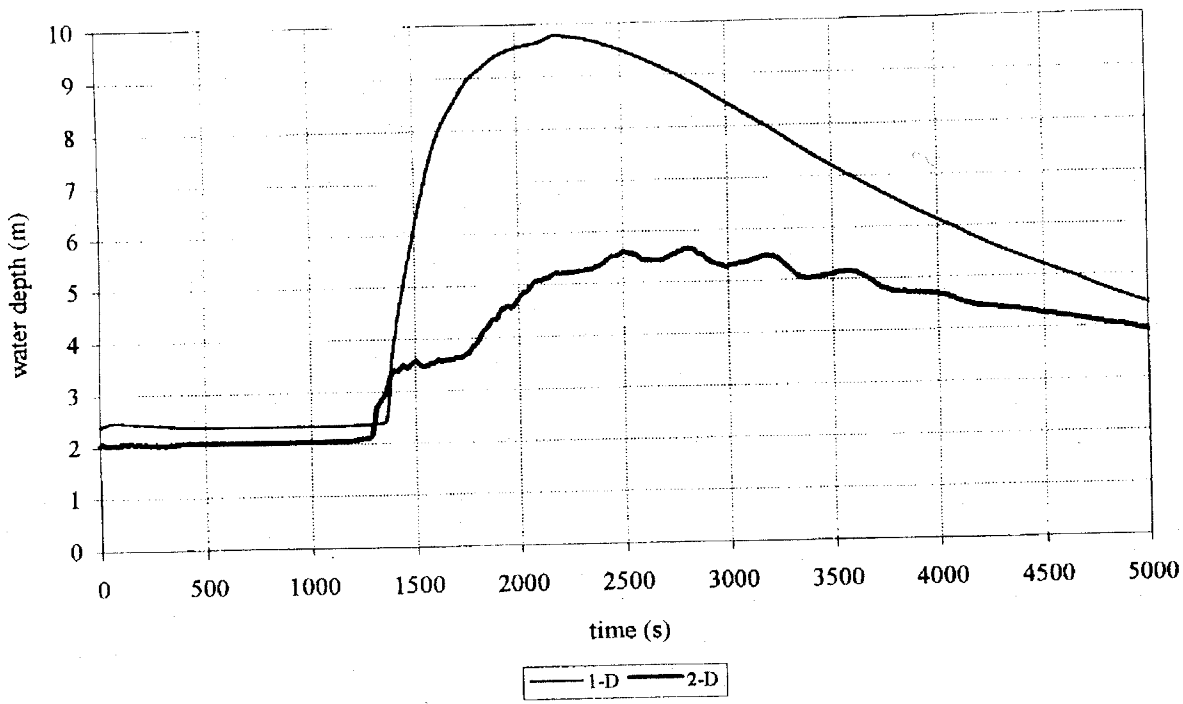

Fig. 4 - Comparison between 1-D and 2-D results downstream an enlargement

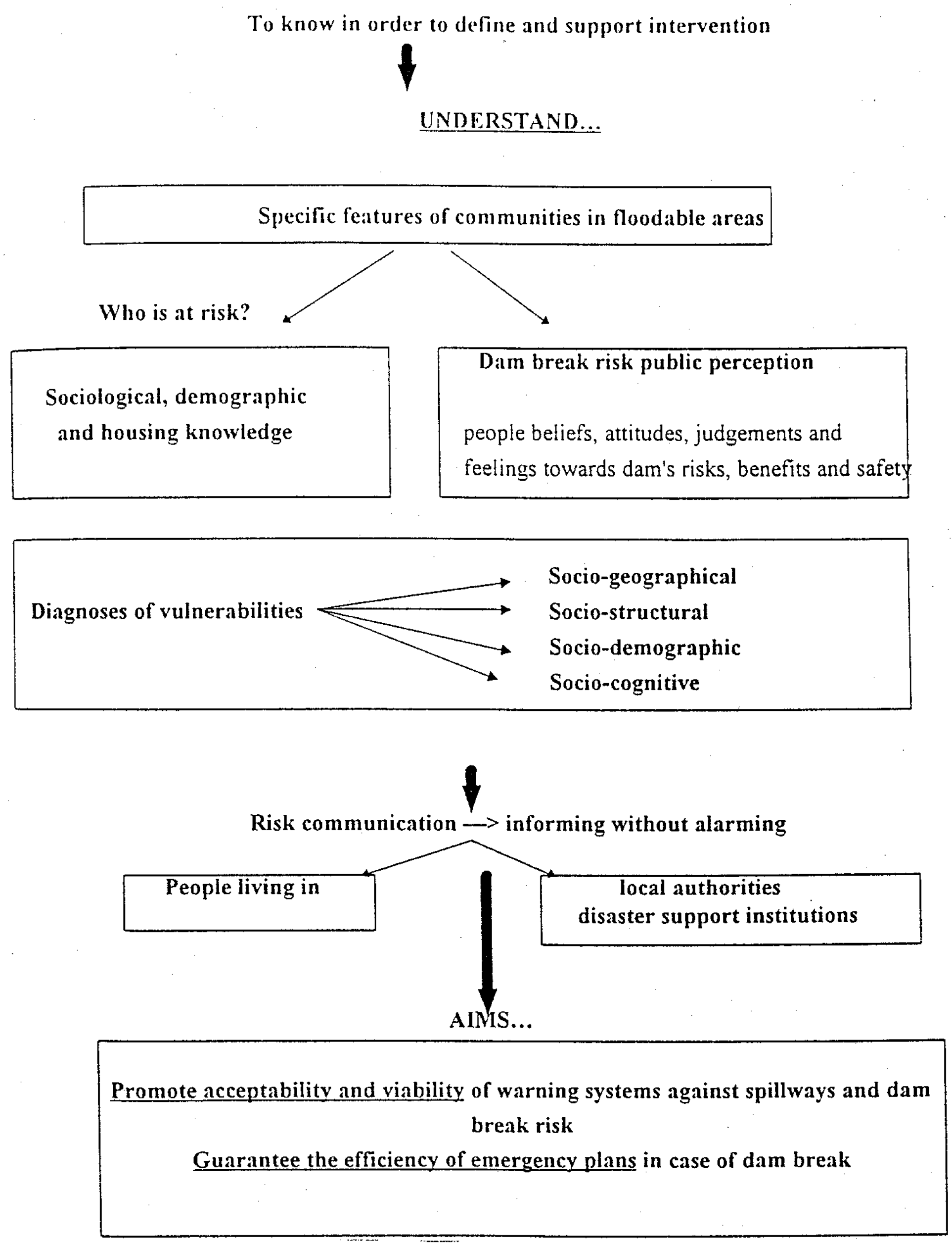

Fig. 5 - Social sciences contributions to dams and safety management at downstream valleys

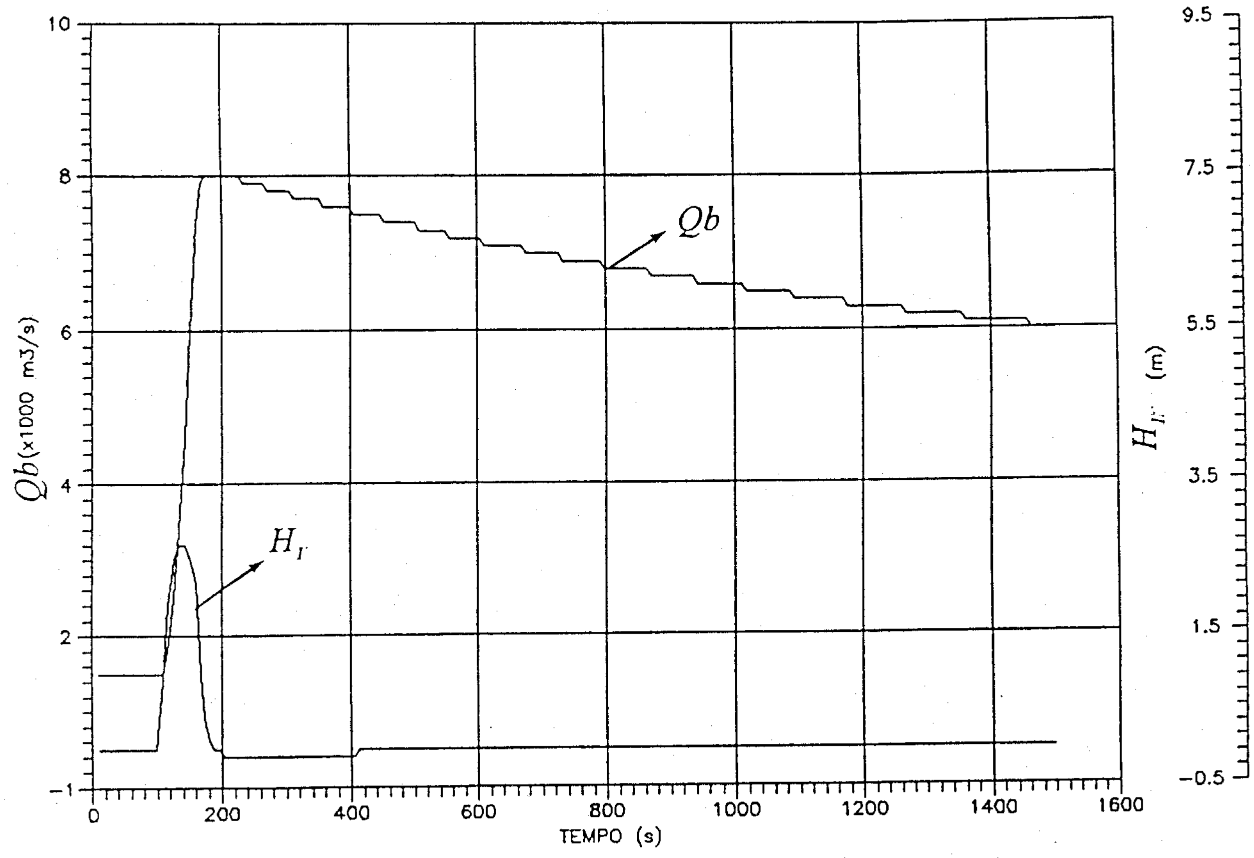

Fig. 6 - Inertia head H_I and breach outflow Q_b. Example of a numerical simulation

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